

1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 1997. A summary of these estimates is provided in Table 1-4 and Table 1-5 by gas and source category. The emission estimates in these tables are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.^{1,2} This report also discusses the methods and data used to calculate these emission estimates.

In June of 1992, the United States signed the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the UNFCCC is “to achieve...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.”^{3,4}

Parties to the Convention, by signing, make commitments “to develop, periodically update, publish and make available...national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies...”⁵ The United States views this report as an opportunity to fulfill this commitment under UNFCCC.

In 1988, preceding the creation of the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The charter of the IPCC is to assess available scientific information on climate change, assess the environmental and socio-economic impacts of climate change, and formulate response strategies (IPCC 1996). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries corroborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The *Revised 1996 IPCC Guidelines* were accepted by the IPCC at its Twelfth Session (Mexico City, 11-13 September 1996). The information provided in this inventory is presented in accordance with these guidelines, unless otherwise noted. Additionally, in order to fully comply with the *Revised 1996 IPCC Guidelines*, the United States has provided a copy of the IPCC reporting tables in Annex N and estimates of carbon dioxide emissions from fossil fuel combustion using the IPCC Reference Approach in Annex O.

¹ See the section below entitled *Global Warming Potentials* for an explanation of GWP values.

² See the section below entitled *What is Climate Change?* for an explanation of radiative forcing.

³ The term “anthropogenic”, in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

⁴ Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change.

⁵ Article 4 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change (also identified in Article 12).

Overall, the purpose of an inventory of anthropogenic greenhouse gas emissions is (1) to provide a basis for the ongoing development of methodologies for estimating sources and sinks of greenhouse gases; (2) to provide a common and consistent mechanism through which Parties to the UNFCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change; and (3) as a prerequisite for evaluating the cost-effectiveness and feasibility of pursuing possible mitigation strategies.

What is Climate Change?

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the Earth's climate system.⁶ Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters,⁷ and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 34°C lower (IPCC 1996).

Under the United Nations FCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."⁸ Given that definition, in its 1995 assessment of the science of climate change, the IPCC concluded that:

Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).

The IPCC went on to report in its assessment that the "[g]lobal mean surface temperature [of the Earth] has increased by between about 0.3 and 0.6 °C since the late 19th century..." (IPCC 1996) and finally concluded with the following statement:

Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of the evidence suggests that there is a discernable human influence on global climate (IPCC 1996).

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither play a significant role in this greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

⁶ The Earth's climate system comprises the atmosphere, oceans, biosphere, cryosphere, and geosphere.

⁷ For example, eccentricity, precession, and inclination.

⁸ Article 1 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change.

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, emitted solely by human activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. Other fluorine containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). There are also several gases that, although they do not have a direct radiative forcing effect, do influence the formation and destruction of ozone, which does have such a terrestrial radiation absorbing effect. These gases—referred to here as ozone precursors—include carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs).⁹ Aerosols—extremely small particles or liquid droplets often produced by emissions of sulfur dioxide (SO₂)—can also affect the absorptive characteristics of the atmosphere.

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropo-

genic activities, however, could have positive or negative feedback effects on these natural systems.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H₂O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well-mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation.

Carbon Dioxide (CO₂). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO₂. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere, as of 1994, increased from approximately 280 parts per million by volume (ppmv) in pre-industrial¹⁰ times to 358 ppmv, a 28 percent increase (IPCC 1996).¹¹ The IPCC has stated that “[t]here is no doubt that this increase is largely due to human activities, in particular fossil fuel combustion...” (IPCC 1996). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

⁹ Also referred to in the U.S. Clean Air Act as “criteria pollutants.”

In its latest scientific assessment, the IPCC also stated that “[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth’s surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved” (IPCC 1996).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4 , as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. The average global concentration of methane in the atmosphere was 1,720 parts per billion by volume (ppbv) in 1994, a 145 percent increase from the pre-industrial concentration of 700 ppbv (IPCC 1996). It is estimated that 60 to 80 percent of current CH_4 emissions are the result of anthropogenic activities. Carbon isotope measurements indicate that roughly 20 percent of methane emissions are from fossil fuel consumption, and an equal percentage is produced by natural wetlands, which will likely increase with rising temperatures and rising microbial action (IPCC 1996).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2 . Increasing emissions of methane, though, reduces the concentration of OH, and thereby the rate of further methane removal (IPCC 1996).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile sources; adipic (nylon) and nitric acid production; wastewater treatment and

waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N_2O) in 1994 was about 312 parts per billion by volume (ppbv), while pre-industrial concentrations were roughly 275 ppbv. The majority of this 13 percent increase has occurred after the pre-industrial period and is most likely due to anthropogenic activities (IPCC 1996). Nitrous oxide is removed from the atmosphere primarily by the photolytic action of sunlight in the stratosphere.

Ozone (O_3). Ozone is present in both the upper stratosphere,¹² where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere¹³, where it is the main component of anthropogenic photochemical “smog”. During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996).

Tropospheric ozone, which is also a greenhouse gas, is produced from the oxidation of methane and from reactions with precursor gases such as carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). This latter group of ozone precursors are included in the category referred to as “criteria pollutants” in the United States under the Clean Air Act¹⁴ and its subsequent amendments. The tropospheric concentrations of both ozone and these precursor gases are short-lived and, therefore, spatially variable.

Halocarbons. Halocarbons are for the most part man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons, methyl bromide, and

¹⁰ The pre-industrial period is considered as the time preceding the year 1750 (IPCC 1996).

¹¹ Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750-1750), a time of relative climate stability, fluctuated by about ± 10 ppmv around 280 ppmv (IPCC 1996).

¹² The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone-layer. The ozone-layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

¹³ The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

hydrobromofluorocarbons (HBFCs)—result in stratospheric ozone depletion and are therefore controlled under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the *Montreal Protocol*, the United States phased-out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the *Protocol*, a cap was placed on the production and importation of HCFCs by non-Article 5¹⁵ countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the *Montreal Protocol* and its Amendments are not covered by the UNFCCC; however, they are reported in this inventory under Annex K.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) are not ozone depleting substances, and therefore are not covered under the *Montreal Protocol*. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 1996). PFCs and SF₆ are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs, and SF₆ is also small; however, because they have extremely long atmospheric lifetimes, their concentrations tend to irreversibly accumulate in the atmosphere.

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH₄ and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radi-

cal) that would otherwise assist in destroying CH₄ and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO₂. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO₂) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects. (NO_x emissions injected higher in the stratosphere¹⁶ can lead to stratospheric ozone depletion.) Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires), fossil fuel combustion, and, in the stratosphere, from nitrous oxide (N₂O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity or by anthropogenic processes such as fuel combustion. Their effect upon radiative forcing is to both absorb radiation and to alter cloud formation, thereby affecting the reflectivity (i.e., albedo) of the Earth. Aerosols are removed from the atmosphere primarily by precipitation, and generally have short atmospheric lifetimes. Like ozone precursors, aerosol concentrations and composition vary by region (IPCC 1996).

¹⁴ [42 U.S.C § 7408, CAA § 108]

¹⁵ Article 5 of the *Montreal Protocol* covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg of certain ozone depleting substances (weighted by their ozone depleting potential) receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

¹⁶ Primarily from fuel combustion emissions from high altitude supersonic aircraft.

Anthropogenic aerosols in the troposphere are primarily the result of sulfur dioxide (SO₂)¹⁷ emissions from fossil fuel and biomass burning. Overall, aerosols tend to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions.¹⁸ Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996). Emissions of sulfur dioxide are provided in Annex L of this report.

Global Warming Potentials

A Global Warming Potential (GWP) is intended as a quantified measure of the relative radiative forcing impacts of a particular greenhouse gas (see Table 1-1). It is defined as the cumulative radiative forcing—both direct and indirect effects—over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produces a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. The reference gas used is CO₂, in which case GWP weighted emissions are measured in million metric tons of carbon equivalents (MMTCE). Carbon comprises 12/44ths of carbon dioxide by weight. In order to convert emissions reported in teragrams (Tg) of a gas to MMTCE, the following equation is used:

$$\text{MMTCE} = (\text{Tg of gas}) \times (\text{GWP}) \times \left(\frac{12}{44}\right)$$

where,

MMTCE = Million Metric Tons of Carbon Equivalents

Tg = Teragrams (equivalent to million metric tons)

GWP = Global Warming Potential

$\left(\frac{12}{44}\right)$ = Carbon to carbon dioxide molecular weight ratio.

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available.

*In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons.*¹⁹

Greenhouse gases with long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, tropospheric ozone, ozone precursors (e.g., NO_x, CO, and NMVOCs), and tropospheric aerosols (e.g., SO₂ products), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere. Other greenhouse gases not yet listed by the Intergovernmental Panel on Climate Change (IPCC), but are already or soon will be in commercial use include: HFC-245fa, hydrofluoroethers (HFEs), and nitrogen trifluoride (NF₃).

A more detailed technical discussion on the derivation of and uncertainties in GWP values can be found in Annex J.

¹⁷ Sulfur dioxide is a primary anthropogenic contributor to the formation of “acid rain” and other forms of atmospheric acid deposition.

¹⁸ Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

¹⁹ Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session; held at Geneva from 8 to 19 July 1996; Addendum; Part Two: Action taken by the Conference of the Parties at its second session; Decision 9/CP.2; Communications from Parties included in Annex I to the Convention: guidelines, schedule and process for consideration; Annex: Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention; p. 18.

Table 1-1: Global Warming Potentials and Atmospheric Lifetimes (Years)

Gas	Atmospheric Lifetime	GWP ^a
Carbon dioxide (CO ₂)	50-200	1
Methane (CH ₄) ^b	12 ± 3	21
Nitrous oxide (N ₂ O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF ₄	50,000	6,500
C ₂ F ₆	10,000	9,200
C ₄ F ₁₀	2,600	7,000
C ₆ F ₁₄	3,200	7,400
SF ₆	3,200	23,900

Source: (IPCC 1996)

^a 100 year time horizon

^b The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO₂ is not included.

Recent Trends in U.S. Greenhouse Gas Emissions

Total U.S. greenhouse gas (GHG) emissions rose in 1997 to 1,813.6 million metric tons of carbon equivalents (MMTCE) (11.1 percent above 1990 baseline levels). The single year increase in emissions from 1996 to 1997 was 1.3 percent (23.1 MMTCE), down from the previous year's increase of 3.3 percent. Figure 1-1 through Figure 1-3 illustrate the overall trends in total U.S. emissions by gas, annual changes, and absolute changes since 1990.

The largest source of U.S. GHG emissions was carbon dioxide (CO₂) from fossil fuel combustion, which accounted for 81 percent of weighted emissions in 1997. Emissions from this source grew by 11 percent (138.8 MMTCE) over the from 1990 to 1997 and were responsible for over three-quarters of the increase in national emissions during this period. The annual increase in CO₂ emissions from this source was 1.3 percent in 1997, also down from the previous year's high when increased fossil fuel consumption drove up emissions by 3.6 percent.

The dramatic increase in fossil fuel combustion-related CO₂ emissions in 1996 was primarily a function of two factors: 1) fuel switching by electric utilities from natural gas to more carbon intensive coal as gas prices rose sharply due to weather conditions, which drove up residential consumption of natural gas for heating; and 2) higher petroleum consumption for transportation. In 1997, by comparison, electric utility natural gas consumption rose to regain much of the previous year's decline as the supply available rose due to lower residential consumption. Despite this increase in natural gas consumption by utilities and relatively stagnant U.S. electricity consumption, coal consumption rose in 1997 to offset the temporary shut-down of several nuclear power plants. Petroleum consumption for transportation activities in 1997 also grew by less than one per-

Figure 1-1

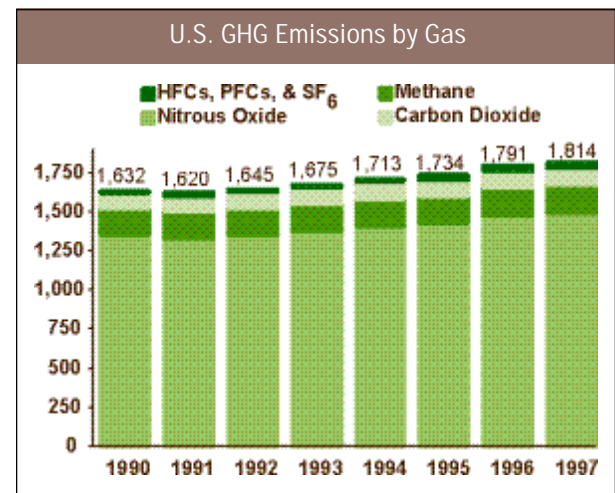


Figure 1-2

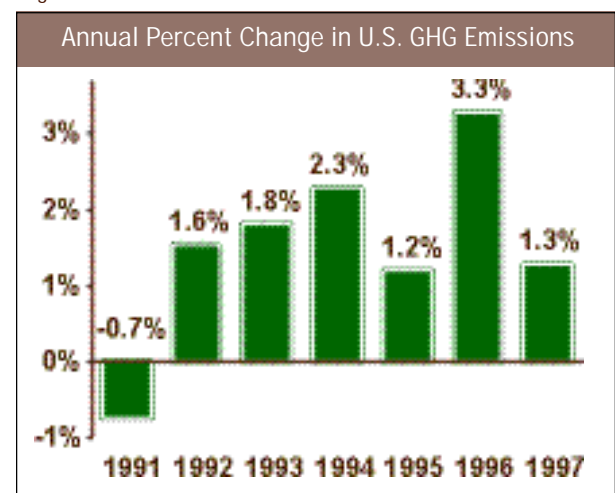
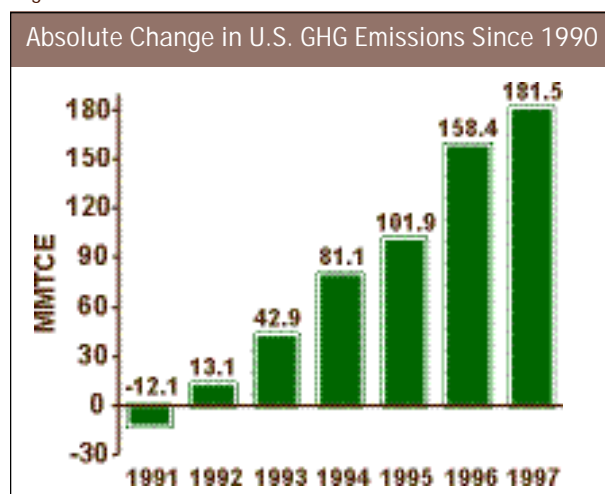


Figure 1-3



cent, compared to over three percent the previous year (see Table 1-2). The annual increase of CO₂ emissions from petroleum in 1997 is based on motor gasoline sales data from the U.S. Energy Information Administration; it is expected to be revised upward with the publication of future energy statistics.

Other significant trends in emissions from additional source categories over the eight year period from 1990 through 1997 included the following:

- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased dramatically (by 14.4 MMTCE). This increase was partly offset, however, by reductions in PFC emissions from aluminum production (41 percent) and HFC emissions from HCFC-22 production (14 percent), both as a result of voluntary industry emission reduction efforts and, in the former case, from falling domestic aluminum production.
- Combined N₂O and CH₄ emissions from mobile source fossil fuel combustion rose by 3.9 MMTCE (26 percent), primarily due to increased rates of N₂O generation in highway vehicles.
- Methane emissions from the decomposition of waste in municipal and industrial landfills rose by 10.5 MMTCE (19 percent) as the amount of organic matter in landfills steadily accumulated.
- Emissions from coal mining dropped by 5.2 MMTCE (21 percent) as the use of methane from degasification systems increased significantly.

Table 1-2: Annual Percent Change in CO₂ Emissions from Fossil Fuel Combustion for Selected Sectors and Fuels

Sector	Fuel Type	1995 to 1996	1996 to 1997
Electric Utility	Coal	5.7%	2.9%
Electric Utility	Natural Gas	-14.6%	8.7%
Residential	Natural Gas	8.1%	-4.4%
Transportation*	Petroleum	3.4%	0.3%

* Excludes emissions from International Bunker Fuels.

- Nitrous oxide emissions from agricultural soil management increased by 8.8 MMTCE (13 percent) as fertilizer consumption and cultivation of nitrogen fixing crops rose.
- An additional domestic adipic acid plant installed emission control systems in 1997; this was estimated to have resulted in a 1.4 MMTCE (27 percent) decline in emissions from 1996 to 1997 despite an increase in production.

Overall, from 1990 to 1997 total emissions of CO₂, CH₄, and N₂O increased by 143.5 (11 percent), 9.7 (6 percent), and 13.4 MMTCE (14 percent), respectively. During the same period, weighted emissions of HFCs, PFCs, and SF₆ rose by 14.9 MMTCE (67 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF₆ are significant because of their extremely high Global Warming Potentials and, in the cases of PFCs and SF₆, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, which was estimated to be 11 percent of total emissions in 1997.

As an alternative, emissions can be aggregated across gases by the IPCC defined sectors, referred to here as chapters. Over the eight year period of 1990 to 1997, total emissions in the Energy, Industrial Processes, Agriculture, and Waste chapters climbed by 140.2 (10 percent), 17.6 (39 percent), 13.0 (11 percent), and 10.8 MMTCE (18 percent), respectively. Estimates of the quantity of carbon sequestered in the Land-Use Change and Forestry chapter, although based on projections, declined in absolute value by 103.0 MMTCE (33 percent).

Box 1-1: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

There are several ways to assess a nation's greenhouse gas emitting intensity. These measures of intensity could be based on aggregate energy consumption because energy-related activities are the largest sources of emissions, on fossil fuel consumption only because almost all energy-related emissions involve the combustion of fossil fuels, on electricity consumption because electric utilities were the largest sources of U.S. greenhouse gas emissions in 1997, on total gross domestic product as a measure of national economic activity, or on a per capita basis. Depending upon which of these measures was used, the United States could appear to have reduced or increased its national greenhouse gas intensity. Table 1-3 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the U.S. have grown at an average annual rate of 1.5 percent since 1990. This rate is slightly slower than that for total energy or fossil fuel consumption—thereby indicating an improved or lower greenhouse gas emitting intensity—and much slower than that for either electricity consumption or overall gross domestic product. Emissions, however, are growing faster than national population, thereby indicating a worsening or higher greenhouse gas emitting intensity on a per capita basis (see Figure 1-4). Overall, atmospheric CO₂ concentrations—a function of many complex anthropogenic and natural processes—are increasing at 0.4 percent per year.

Table 1-3: Recent Trends in Various U.S. Data (Index 1990=100)

Variable	1990	1991	1992	1993	1994	1995	1996	1997	Growth Rate ^g
GHG Emissions ^a	100	99	101	103	105	106	110	111	1.5%
Energy Consumption ^b	100	100	101	104	106	108	112	112	1.6%
Fossil Fuel Consumption ^c	100	99	101	104	106	107	110	112	1.6%
Electricity Consumption ^c	100	102	102	105	108	111	114	115	2.0%
GDP ^d	100	99	102	104	108	110	114	118	2.5%
Population ^e	100	101	102	103	104	105	106	107	1.0%
Atmospheric CO ₂ Concentration ^f	100	100	101	101	101	102	102	103	0.4%

^a GWP weighted values

^b Energy content weighted values. Source: DOE/EIA

^c Source: DOE/EIA

^d Gross Domestic Product in chained 1992 dollars (BEA 1998)

^e (U.S. Census Bureau 1998)

^f Mauna Loa Observatory, Hawaii (Keeling and Whorf 1998)

^g Average annual growth rate

Figure 1-4

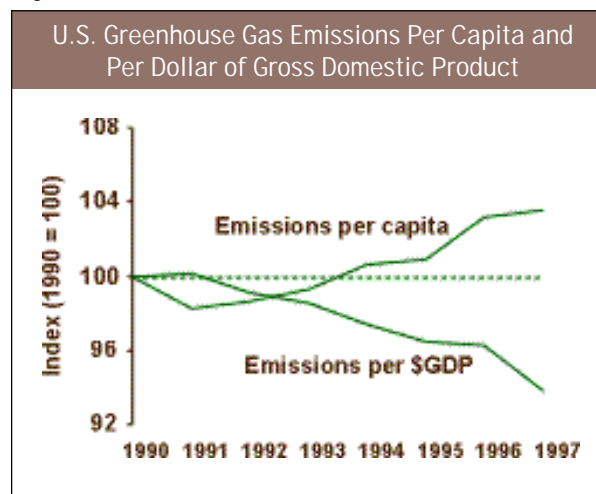


Table 1-4 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of MMTCE, while unweighted gas emissions and sinks in teragrams (Tg)

are provided in Table 1-5. Alternatively, emissions and sinks are aggregated by chapter in Table 1-6 and Figure 1-5.

Table 1-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMTCE)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997
CO₂	1,344.3	1,329.8	1,349.6	1,379.2	1,403.5	1,419.2	1,469.3	1,487.9
Fossil Fuel Combustion	1,327.2	1,312.6	1,332.4	1,360.6	1,383.9	1,397.8	1,447.7	1,466.0
Natural Gas Flaring	2.3	2.6	2.6	3.5	3.6	4.5	4.3	4.2
Cement Manufacture	8.9	8.7	8.8	9.3	9.6	9.9	9.9	10.2
Lime Manufacture	3.3	3.2	3.3	3.4	3.5	3.7	3.8	3.9
Limestone and Dolomite Use	1.4	1.3	1.2	1.1	1.5	1.9	2.0	2.1
Soda Ash Manufacture and Consumption	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Carbon Dioxide Consumption	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Land-Use Change and Forestry (Sink) ^a	(311.5)	(311.5)	(311.5)	(208.6)	(208.6)	(208.6)	(208.6)	(208.6)
International Bunker Fuels ^b	27.1	27.8	29.0	29.9	27.4	25.4	25.4	26.6
CH₄	169.9	171.0	172.5	172.0	175.5	178.6	178.3	179.6
Stationary Sources	2.3	2.4	2.4	2.4	2.4	2.5	2.5	2.2
Mobile Sources	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Coal Mining	24.0	22.8	22.0	19.2	19.4	20.3	18.9	18.8
Natural Gas Systems	32.9	33.3	33.9	34.1	33.5	33.2	33.7	33.5
Petroleum Systems	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6
Petrochemical Production	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Silicon Carbide Production	+	+	+	+	+	+	+	+
Enteric Fermentation	32.7	32.8	33.2	33.6	34.5	34.9	34.5	34.1
Manure Management	14.9	15.4	16.0	16.1	16.7	16.9	16.6	17.0
Rice Cultivation	2.5	2.5	2.8	2.5	3.0	2.8	2.5	2.7
Agricultural Residue Burning	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Landfills	56.2	57.6	57.8	59.7	61.6	63.6	65.1	66.7
Wastewater Treatment	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
International Bunker Fuels ^b	+	+	+	+	+	+	+	+
N₂O	95.7	97.6	100.1	100.4	108.3	105.4	108.2	109.0
Stationary Sources	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.1
Mobile Sources	13.6	14.2	15.2	15.9	16.7	17.0	17.4	17.5
Adipic Acid Production	4.7	4.9	4.6	4.9	5.2	5.2	5.4	3.9
Nitric Acid Production	3.3	3.3	3.4	3.5	3.7	3.7	3.9	3.8
Manure Management	2.6	2.8	2.8	2.9	2.9	2.9	3.0	3.0
Agricultural Soil Management	65.3	66.2	68.0	67.0	73.4	70.2	72.0	74.1
Agricultural Residue Burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Human Sewage	2.1	2.1	2.2	2.2	2.2	2.3	2.3	2.3
Waste Combustion	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
International Bunker Fuels ^b	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
HFCs, PFCs, and SF₆	22.2	21.6	23.0	23.4	25.9	30.8	34.7	37.1
Substitution of Ozone Depleting Substances	0.3	0.2	0.4	1.4	4.0	9.5	11.9	14.7
Aluminum Production	4.9	4.7	4.1	3.5	2.8	2.7	2.9	2.9
HCFC-22 Production	9.5	8.4	9.5	8.7	8.6	7.4	8.5	8.2
Semiconductor Manufacture	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.3
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0
Magnesium Production and Processing	1.7	2.0	2.2	2.5	2.7	3.0	3.0	3.0
Total Emissions	1,632.1	1,620.0	1,645.2	1,675.0	1,713.2	1,733.9	1,790.5	1,813.6
Net Emissions (Sources and Sinks)	1,320.6	1,308.5	1,333.7	1,466.5	1,504.7	1,525.4	1,582.0	1,605.0

+ Does not exceed 0.05 MMTCE

^a Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.

^b Emissions from International Bunker Fuels are not included in totals.

Note: Totals may not sum due to independent rounding.

Table 1-5: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997
CO₂	4,929.2	4,875.8	4,948.5	5,057.0	5,146.1	5,203.6	5,387.4	5,455.6
Fossil Fuel Combustion	4,866.2	4,812.8	4,885.4	4,988.7	5,074.4	5,125.1	5,308.3	5,375.2
Natural Gas Flaring	8.4	9.6	9.4	13.0	13.1	16.4	15.7	15.2
Cement Manufacture	32.6	31.9	32.1	33.9	35.4	36.1	36.4	37.5
Lime Manufacture	11.9	11.7	12.1	12.4	12.8	13.6	14.1	14.2
Limestone and Dolomite Use	5.1	4.9	4.5	4.1	5.5	7.0	7.5	7.8
Soda Ash Manufacture and Consumption	4.1	4.0	4.1	4.0	4.0	4.3	4.3	4.4
Carbon Dioxide Consumption	0.8	0.8	0.9	0.9	0.9	1.0	1.1	1.2
Land-Use Change and Forestry (Sink) ^a	(1,142.2)	(1,142.2)	(1,142.2)	(764.7)	(764.7)	(764.7)	(764.7)	(764.7)
International Bunker Fuels ^b	99.3	101.9	106.4	109.6	100.4	93.3	93.0	97.5
CH₄	29.7	29.9	30.1	30.0	30.7	31.2	31.1	31.4
Stationary Sources	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mobile Sources	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Coal Mining	4.2	4.0	3.8	3.4	3.4	3.6	3.3	3.3
Natural Gas Systems	5.7	5.8	5.9	5.9	5.8	5.8	5.9	5.8
Petroleum Systems	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Silicon Carbide Production	+	+	+	+	+	+	+	+
Enteric Fermentation	5.7	5.7	5.8	5.9	6.0	6.1	6.0	6.0
Manure Management	2.6	2.7	2.8	2.8	2.9	3.0	2.9	3.0
Rice Cultivation	0.4	0.4	0.5	0.4	0.5	0.5	0.4	0.5
Agricultural Residue Burning	+	+	+	+	+	+	+	+
Landfills	9.8	10.0	10.1	10.4	10.8	11.1	11.4	11.6
Wastewater Treatment	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels ^b	+	+	+	+	+	+	+	+
N₂O	1.1	1.2	1.2	1.2	1.3	1.2	1.3	1.3
Stationary Source	+	+	+	+	+	+	+	+
Mobile Sources	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Adipic Acid	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+
Nitric Acid	+	+	+	+	+	+	+	+
Manure Management	+	+	+	+	+	+	+	+
Agricultural Soil Management	0.8	0.8	0.8	0.8	0.9	0.8	0.9	0.9
Agricultural Residue Burning	+	+	+	+	+	+	+	+
Human Sewage	+	+	+	+	+	+	+	+
Waste Combustion	+	+	+	+	+	+	+	+
International Bunker Fuels ^b	+	+	+	+	+	+	+	+
HFCs, PFCs, and SF₆	M	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances	M	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M	M
HCFC-22 Production ^c	+	+	+	+	+	+	+	+
Semiconductor Manufacture	M	M	M	M	M	M	M	M
Electrical Transmission and Distribution ^d	+	+	+	+	+	+	+	+
Magnesium Production and Processing ^d	+	+	+	+	+	+	+	+
NO_x	21.1	21.2	21.5	21.7	22.0	21.4	21.2	21.3
CO	83.1	84.8	81.8	81.7	85.7	76.7	78.3	75.2
NMVOCs	18.7	18.8	18.5	18.6	19.2	18.4	17.2	17.1

+ Does not exceed 0.05 Tg

M Mixture of multiple gases

^a Sinks are not included in CO₂ emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.^b Emissions from International Bunker Fuels are not included in totals.^c HFC-23 emitted^d SF₆ emitted

Note: Totals may not sum due to independent rounding.

Figure 1-5

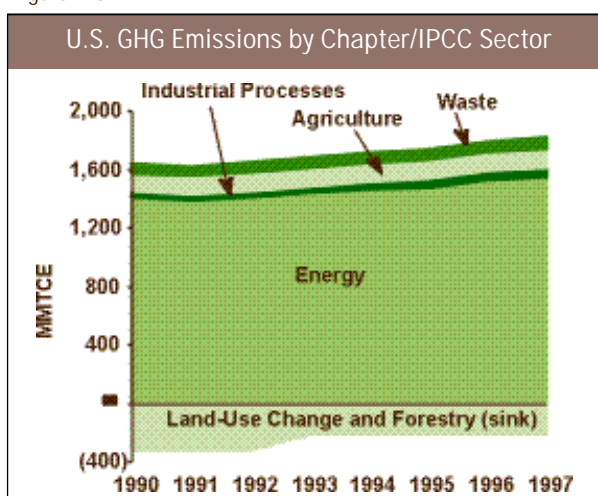


Table 1-6: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMTCE)

Chapter/IPCC Sector	1990	1991	1992	1993	1994	1995	1996	1997
Energy	1,409.0	1,394.6	1,415.2	1,442.6	1,466.3	1,482.1	1,531.6	1,549.2
Industrial Processes	45.4	44.8	46.0	47.2	51.2	57.0	61.6	63.0
Agriculture	118.4	120.0	123.1	122.4	130.9	128.0	128.9	131.4
Land-Use Change and Forestry (Sink)*	(311.5)	(311.5)	(311.5)	(208.6)	(208.6)	(208.6)	(208.6)	(208.6)
Waste	59.2	60.6	60.9	62.8	64.8	66.9	68.4	70.0
Total Emissions	1,632.1	1,620.0	1,645.2	1,675.0	1,713.2	1,733.9	1,790.5	1,813.6
Net Emissions (Sources and Sinks)	1,320.6	1,308.5	1,333.7	1,466.5	1,504.7	1,525.4	1,582.0	1,605.0

* Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.

Note: Totals may not sum due to independent rounding.

Box 1-2: Greenhouse Gas Emissions from Transportation Activities

Motor vehicle usage is increasing all over the world, including in the United States. Since the 1970s, the number of highway vehicles registered in the United States has increased faster than the overall population, according to the Federal Highway Administration. Likewise, the number of miles driven—up 18 percent from 1990 to 1997—and gallons of gasoline consumed each year in the United States have increased relatively steadily since the 1980s, according to the Energy Information Administration. These increases in motor vehicle usage are the result of a confluence of factors including population growth, economic growth, increasing urban sprawl, and low fuel prices.

One of the unintended consequences of these changes is a slowing of progress toward cleaner air in both urban and rural parts of the country. Passenger cars, trucks, motorcycles, and buses emit significant quantities of air pollutants with local, regional, and global effects. Motor vehicles are major sources of carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄), nonmethane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), nitrous oxide (N₂O), and hydrofluorocarbons (HFCs). Motor vehicles are also important contributors to many serious air pollution problems, including ground level ozone or smog, acid rain, fine particulate matter, and global warming. Within the United States and abroad, government agencies have taken strong actions to reduce these emissions. Since the 1970s, the EPA has reduced lead in gasoline, developed strict emission standards for new passenger cars and trucks, directed states to enact comprehensive motor vehicle emission control programs, required inspection and maintenance programs, and more recently, introduced the use of reformulated gasoline to mitigate the air pollution impacts from motor vehicles. New vehicles are now equipped with advanced emissions controls, which are designed to reduce emissions of nitrogen oxides, hydrocarbons, and carbon monoxide.

This report reflects new data on the role that automotive catalytic converters play in emissions of N₂O, a powerful greenhouse gas. The EPA's Office of Mobile Sources has conducted a series of tests in order to measure the magnitude of N₂O emissions from gasoline-fueled passenger cars and light-duty trucks equipped with catalytic converters. Results show that N₂O emissions are lower than the IPCC default factors, and the United States has shared this data with the IPCC. In this report, new emission factors developed from these measurements and from previously published literature were used to calculate emissions from mobile sources in the United States (see Annex C).

Table 1-7 summarizes greenhouse gas emissions from all transportation-related activities. Overall, transportation activities—excluding international bunker fuels—accounted for an almost constant 26 percent of total U.S. greenhouse gas emissions from 1990 to 1997. These emissions were primarily CO₂ from fuel combustion, which increased by 10 percent from 1990 to 1997. However, because of larger increases in N₂O and HFC emissions during this period, overall emissions from transportation activities actually increased by 12 percent.

Table 1-7: Transportation-Related Greenhouse Gas Emissions (MMTCE)

Gas/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997
CO₂	405.0	396.7	402.4	406.8	422.1	430.7	445.3	446.5
Passenger Cars ^a	169.3	167.8	172.0	173.5	172.5	175.6	160.8	162.6
Light-Duty Trucks ^a	77.5	77.2	77.2	80.5	87.2	89.2	109.9	111.1
Other Trucks	57.3	55.1	56.7	59.9	62.7	64.2	68.3	69.5
Buses	2.7	2.9	2.9	3.1	3.3	3.5	3.0	3.0
Aircraft	50.5	48.4	47.4	47.6	49.6	48.3	50.5	50.1
Boats and Vessels	16.4	15.9	16.4	11.7	13.9	16.8	18.5	15.4
Locomotives	7.5	6.9	7.4	6.8	8.0	8.1	8.8	9.0
Other ^b	23.8	22.5	22.4	23.8	24.9	24.9	25.5	25.8
International Bunker Fuels ^c	27.1	27.8	29.0	29.9	27.4	25.4	25.4	26.6
CH₄	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Passenger Cars	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6
Light-Duty Trucks	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
Other Trucks and Buses	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Aircraft	+	+	+	+	+	+	+	+
Boats and Vessels	+	+	+	+	+	+	+	+
Locomotives	+	+	+	+	+	+	+	+
Other ^d	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
International Bunker Fuels ^c	+	+	+	+	+	+	+	+
N₂O	13.6	14.2	15.2	15.9	16.7	17.0	17.4	17.5
Passenger Cars	8.7	9.1	9.7	10.1	10.0	10.1	8.9	9.1
Light-Duty Trucks	3.4	3.7	3.9	4.2	5.1	5.2	6.8	6.8
Other Trucks and Buses	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9
Aircraft ^d	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Boats and Vessels	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other ^d	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels ^c	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
HFCs	+	+	0.2	0.7	1.3	2.5	3.6	4.5
Mobile Air Conditioners ^e	+	+	0.2	0.7	1.3	2.5	3.6	4.5
Total^e	420.0	412.3	419.1	424.8	441.5	451.6	467.7	469.9
+ Does not exceed 0.05 MMTCE								
Note: Totals may not sum due to independent rounding.								
^a In 1996, the U.S. Federal Highway Administration modified the definition of light-duty trucks to include minivans and sport utility vehicles. Previously, these vehicles were included under the passenger cars category. Hence the sharp drop in CO ₂ emissions for passenger cars from 1995 to 1996 was observed. This gap, however, was offset by an equivalent rise in CO ₂ emissions from light-duty trucks.								
^b "Other" CO ₂ emissions include motorcycles, construction equipment, agricultural machinery, pipelines, and lubricants.								
^c Emissions from International Bunker Fuels are not included in totals.								
^d "Other" CH ₄ and N ₂ O emissions include motorcycles, construction equipment, agricultural machinery, gasoline-powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel-powered recreational, industrial, lawn and garden, light construction, airport service.								
^e Includes primarily HFC-134a								

Box 1-3: Electric Utility-Related Greenhouse Gas Emissions

Like transportation, activities related to the generation, transmission, and distribution of electricity in the United States result in greenhouse gas emissions. Table 1-8 presents greenhouse gas emissions from electric utility-related activities. Aggregate emissions from electric utilities of all greenhouse gases from electric utilities increased by 11.8 percent from 1990 to 1997, and accounted for just under 30 percent of total U.S. greenhouse emissions during the same period. The majority of these emissions resulted from the combustion of coal in boilers to produce steam that is passed through a turbine to generate electricity. Overall, the generation of electricity results in a larger portion of total U.S. greenhouse gas emissions than any other activity.

Table 1-8: Electric Utility-Related Greenhouse Gas Emissions (MMTCE)

Gas/Fuel Type or Source	1990	1991	1992	1993	1994	1995	1996	1997
CO₂	476.8	473.4	472.5	490.7	494.8	494.1	513.2	532.3
Coal	409.0	407.2	411.8	428.7	430.2	433.0	457.5	470.9
Natural Gas	41.2	41.1	40.7	39.5	44.0	47.2	40.3	43.8
Petroleum	26.6	25.1	19.9	22.5	20.6	14.0	15.4	17.6
Geothermal	0.1	0.1	0.1	0.1	+	+	+	+
CH₄	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Stationary Sources (Utilities)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N₂O	2.0	2.0	2.0	2.1	2.1	2.1	2.2	2.3
Stationary Sources (Utilities)	2.0	2.0	2.0	2.1	2.1	2.1	2.2	2.3
SF₆	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0
Total	484.6	481.4	480.8	499.3	503.7	503.3	522.5	541.7

+ Does not exceed 0.05 MMTCE
Note: Totals may not sum due to independent rounding.

Methodology and Data Sources

Emissions of greenhouse gases from various sources have been estimated using methodologies that are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), except where noted otherwise. To the extent possible, the present U.S. inventory relies on published activity and emission factor data. Depending on the emission source category, *activity data* can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc.; *emission factors* are factors that relate quantities of emissions to an activity. For some sources, IPCC default methodologies and emission factors have been employed. However, for emission sources considered to be major sources in the United States, the IPCC default methodologies were expanded and more comprehensive methods were applied.

Inventory emission estimates from energy consumption and production activities are based primarily on the latest official fuel consumption data from the Energy Information Administration of the Department of Energy (EIA). Emission estimates for NO_x, CO, and NMVOCs were taken directly, except where noted, from the United States Environmental Protection Agency's (EPA) report, *National Air Pollutant Emission Trends 1900 - 1997* (EPA 1998), which is an annual EPA publication that provides the latest estimates of regional and national emissions for ozone precursors (i.e., criteria pollutants). Emissions of these pollutants are estimated by the EPA based on statistical information

about each source category, emission factors, and control efficiencies. While the EPA's estimation methodologies for criteria pollutants are conceptually similar to the IPCC recommended methodologies, the large number of sources EPA used in developing its estimates makes it difficult to reproduce the methodologies from EPA (1997) in this inventory document. In these instances, the sources containing detailed documentation of the methods used are referenced for the interested reader. For agricultural sources, the EPA criteria pollutant emission estimates were supplemented using available activity data from other agencies. Complete documentation of the methodologies and data sources used is provided in conjunction with the discussion of each source and in the various annexes.

Carbon dioxide emissions from fuel combusted in ships or aircraft engaged in the international transport of passengers or cargo are not included in U.S. totals, but are reported separately as international bunkers in accordance with IPCC reporting guidelines (IPCC/UNEP/OECD/IEA 1997). Carbon dioxide emissions from fuel combusted within U.S. territories, however, are included in U.S. totals.

Uncertainty in and Limitations of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, it has several strengths and weaknesses.

First, this inventory by itself does not provide a complete picture of past or future emissions in the United States; it only provides an inventory of U.S. emissions for the years 1990 through 1997. However, the United States believes that common and consistent inventories taken over a period of time can and will contribute to understanding future emission trends. The United States produced its first comprehensive inventory of greenhouse gas emissions and sinks in 1993, and intends to update this inventory annually in conjunction with its commitments under the UNFCCC. The methodologies used to estimate emissions will be periodically updated as methods and information improve, and as further guidance is received from the IPCC.

Secondly, there are uncertainties associated with the emissions estimates. Some of the current estimates, such as those for CO₂ emissions from energy-related activities and cement processing, are considered to be fairly accurate. For other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated limit the scope or accuracy of the estimates presented. Despite these uncertainties, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) require that countries provide single point estimates for each gas and emission or removal source category. Within the discussion of each emission source, specific factors affecting the accuracy of the estimates are discussed.

Finally, while the IPCC methodologies provided in the *Revised 1996 IPCC Guidelines* represent baseline methodologies for a variety of source categories, many of these methodologies continue to be improved and refined as new research and data becomes available. The current U.S. inventory uses the IPCC methodologies when applicable, and supplements them with other available methodologies and data where possible. The United States realizes that additional efforts are still needed to improve methodologies and data collection procedures. Specific areas requiring further research include:

Incorporating excluded emission sources. Quantitative estimates of some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and in-

dustrial processes are not included in the inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex P for a discussion of the sources of greenhouse gas emissions excluded from this report.

Improving the accuracy of emission factors. Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to methane and nitrous oxide emissions from stationary and mobile source fossil fuel combustion are highly uncertain.

Collecting detailed activity data. Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of methane and nitrous oxide from jet aircraft is limited due to a lack of activity data by aircraft type and number of landing and take-off cycles.

Applying Global Warming Potentials. GWP values have several limitations including that they are not applicable to unevenly distributed gases and aerosols such as tropospheric ozone and its precursors. They are also intended to reflect global averages and, therefore, do not account for regional effects. Overall, the main uncertainties in developing GWP values are the estimation of atmospheric lifetimes, assessing indirect effects, choosing the appropriate integration time horizon, and assessing instantaneous radiative forcing effect which is dependent upon existing atmospheric concentrations. According to the IPCC, GWPs typically have an uncertainty of ± 35 percent (IPCC 1996). Additional discussion on the uncertainties related to the use of GWP weighting values can be found in Annex J.

Emissions calculated for the U.S. inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates.

Organization of Report

In accordance with the IPCC guidelines for reporting contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), this U.S. inventory of greenhouse gas emissions is segregated into six sector-specific chapters, listed below in Table 1-9.

Within each chapter, emissions are identified by the anthropogenic activity that is the source of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/IPCC Sector: Overview of emission trends for each IPCC defined sector

Source: Description of source pathway and emission trends from 1990 through 1997

- **Methodology:** Description of analytical methods employed to produce emission estimates
- **Data Sources:** Identification of primary data references, primarily for activity data and emission factors
- **Uncertainty:** Discussion of relevant issues related to the uncertainty in the emission estimates presented

Special attention is given to carbon dioxide from fossil fuel combustion relative to other sources because of its share of emissions relative to other sources. For example, each energy consuming end-use is treated individually. Additional information for certain source categories and other topics is also provided in several Annexes listed in Table 1-10.

Table 1-9: IPCC Sector Descriptions

Chapter/IPCC Sector	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions.
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.
Solvent Use	Emissions, of primarily non-methane volatile organic compounds (NMVOCs), resulting from the use of solvents.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion and sewage emissions, which are addressed under Energy and Waste, respectively.
Land-Use Change and Forestry	Emissions and removals from forest and land-use change activities, primarily carbon dioxide.
Waste	Emissions from waste management activities.

Source: (IPCC/UNEP/OECD/IEA 1997)

Table 1-10: List of Annexes

ANNEX A	Methodology for Estimating Emissions of CO ₂ from Fossil Fuel Combustion	ANNEX H	Methodology for Estimating Methane Emissions from Manure Management
ANNEX B	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Stationary Sources	ANNEX I	Methodology for Estimating Methane Emissions from Landfills
ANNEX C	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Mobile Sources	ANNEX J	Global Warming Potential Values
ANNEX D	Methodology for Estimating Methane Emissions from Coal Mining	ANNEX K	Ozone Depleting Substance Emissions
ANNEX E	Methodology for Estimating Methane Emissions from Natural Gas Systems	ANNEX L	Sulfur Dioxide Emissions
ANNEX F	Methodology for Estimating Methane Emissions from Petroleum Systems	ANNEX M	Complete List of Sources
ANNEX G	Methodology for Estimating Methane Emissions from Enteric Fermentation	ANNEX N	IPCC Reporting Tables
		ANNEX O	IPCC Reference Approach for Estimating CO ₂ Emissions from Fossil Fuel Combustion
		ANNEX P	Sources of Greenhouse Gas Emissions Excluded
		ANNEX Q	Constants, Units, and Conversions
		ANNEX R	Abbreviations
		ANNEX S	Chemical Symbols
		ANNEX T	Glossary